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Weapons radiochemistry and nuclear forensics

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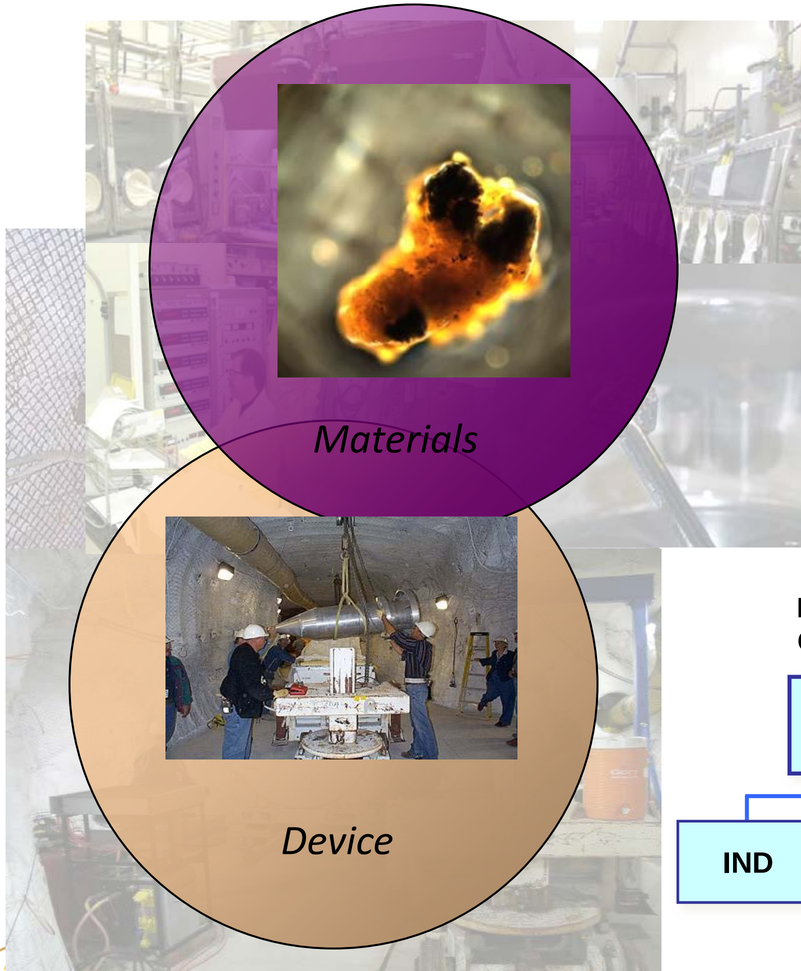
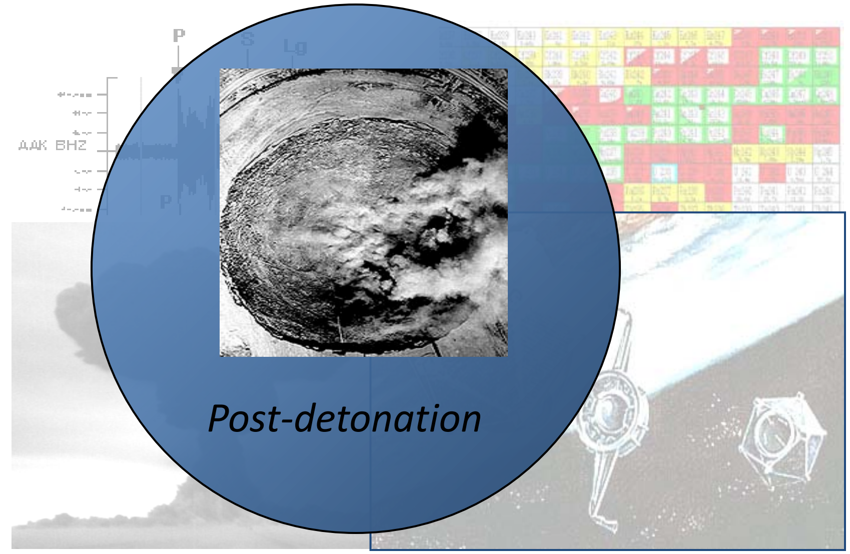
Technical Nuclear Forensics: Recognizes three main types of forensic "events", but includes other subclasses:



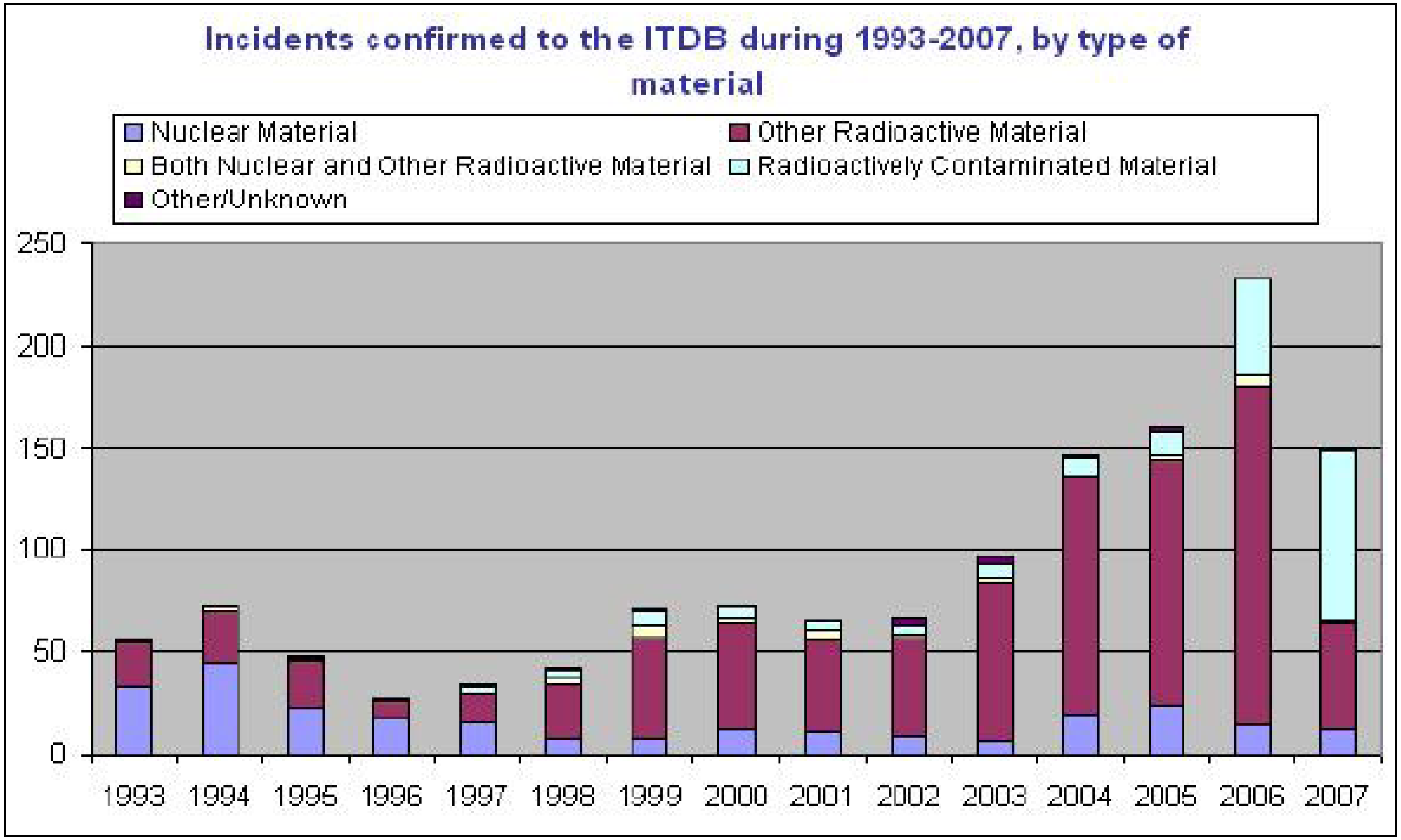


Event Class

- **Interdiction**
  - IND
  - Fissile Material
  - Rad Material
  - Sealed Source
- **Emplaced Source**
- **Non-Explosive RDD**
- **Explosive RDD**
  - Explosive RDD
  - Failed IND
- **Nuclear Yield**

Subclass

For some classes of events, we have real case examples…what about for a postdetonation event?

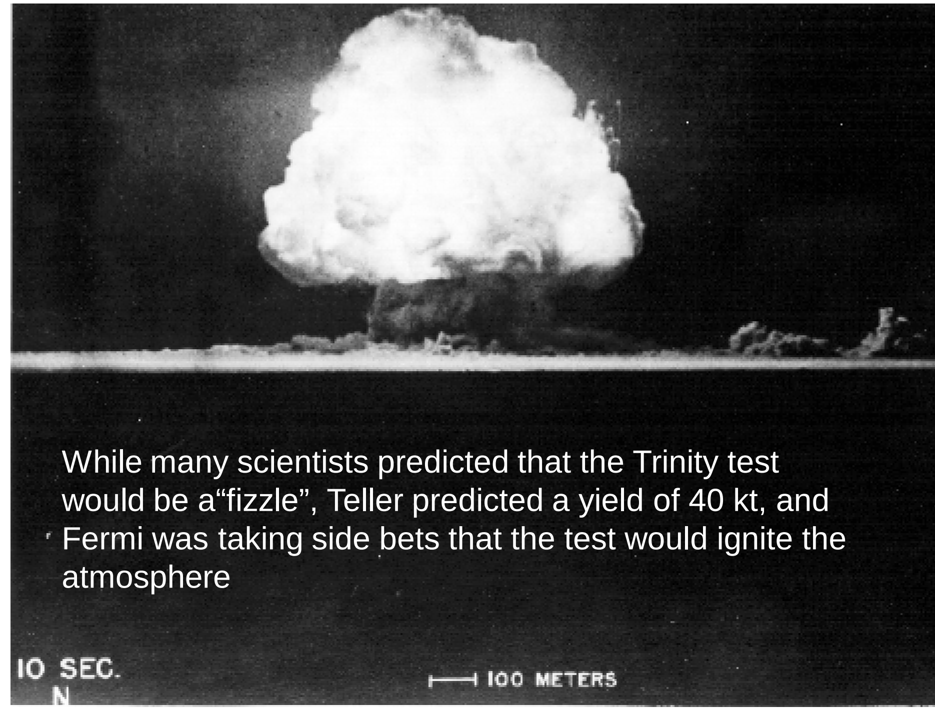


Source – Mayer et al., Actinide Resarch Quarterly, 2007

The genesis of weapons radiochemistry

- *Some time before the Trinity event, it was proposed that radiochemistry could determine the yield of a device:*
  - Assume that the yield is solely due to fission in plutonium
  - In a sample of the debris, determine the amount of fission products relative to “unburned” plutonium to determine the efficiency
  - Given a known mass of fuel, the total number of “fissions” can be determined
  - This can be converted into energy release:

  10^{12} calories = 1 kiloton (~ ¼ mole of fissions)



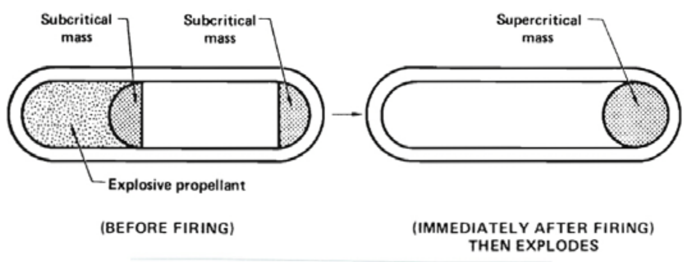
Until the radiochemical data was available, the best estimate of the yield of the device was obtained by Fermi, who dropped small scraps of paper as the blast wave went by

Basics of nuclear explosive devices

- A nuclear explosive device generates a large amount of energy from a small amount of fuel.
- "Yield" to mass ratio is much greater than conventional explosives
- Leaves behind fissile material, fission products, activation products
- Try to create a large multiplication factor – biggest increase in the number of neutrons (fissions) from one generation to the next.
- The resulting energy generated causes the explosion – the trick is to keep the device assembled long enough.

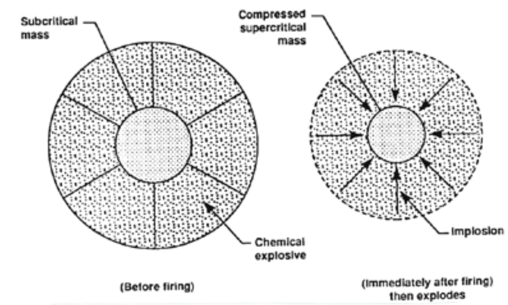
Types of nuclear explosive devices

Gun assembled



- Like "Little Boy"
- Simpler – not tested prior to use
- Not suitable for some fuels

Implosion assembled



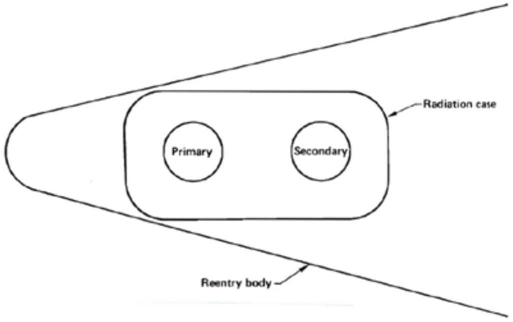
- Like "Fat Man"
- Trinity test
- More challenging to generate an even implosion

- Conditions must exist (quantity, shape, isotopic composition) to have the material exceed the critical mass

Fusion reactions

- Fusion of two very light nuclei can also release energy
- Multiplicity is small; not self-sustaining
- Fusion can be accomplished in accelerators, or at high temperatures and pressures (stars)
- Fusion neutrons provide a high-energy assist, or “boost”, to the fission process (increase fission efficiency)
- More complex design; requires special materials

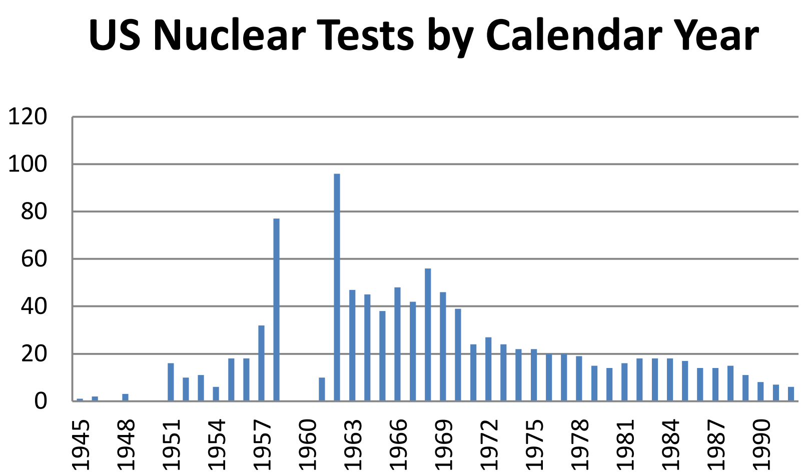
Staged weapon



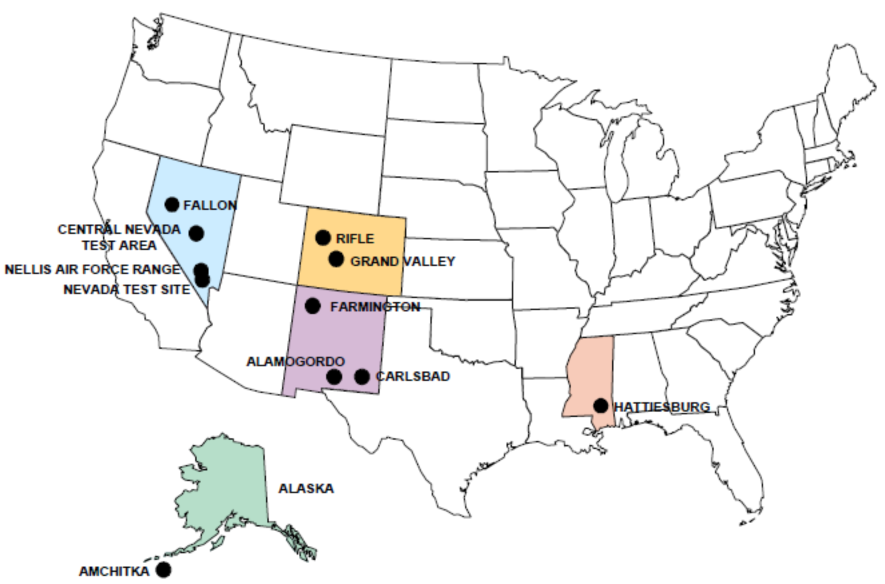
What might be different about weapons materials?

- Nonfissile components kept to a minimum:
  - Maximum amount of fissile isotopes
  - Moderators are bad
    - For fast neutrons, fission (n,f) cross sections are much lower than for thermal neutrons
    - Capture (c) cross sections are also affected, but not as much
    - Certain alloying elements may be present (aids in fabrication)

Weapons radiochemistry was developed during the history of the test program



Source DOE/NV-209-REV15 (2000)



Radiochemistry quantifies device performance, and provides validation data for codes

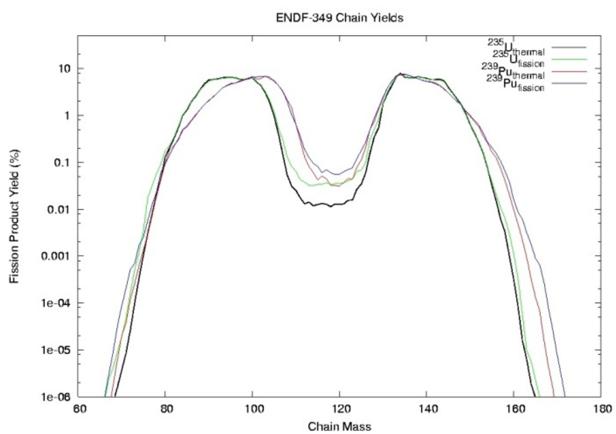
- Radiochemical diagnostics are time integrated measurements
- There are three major classes of analytes that are determined by radiochemistry
  - Actinides
  - Fission Products
  - Activation Products

The radiochemical interpretation of a nuclear event from fission products relies on the ability to determines fissions :

$$N_i = FY_i \quad F = N_i / Y_i$$

N_i = number of atoms of fission product i
Y_i = cumulative fission product yield

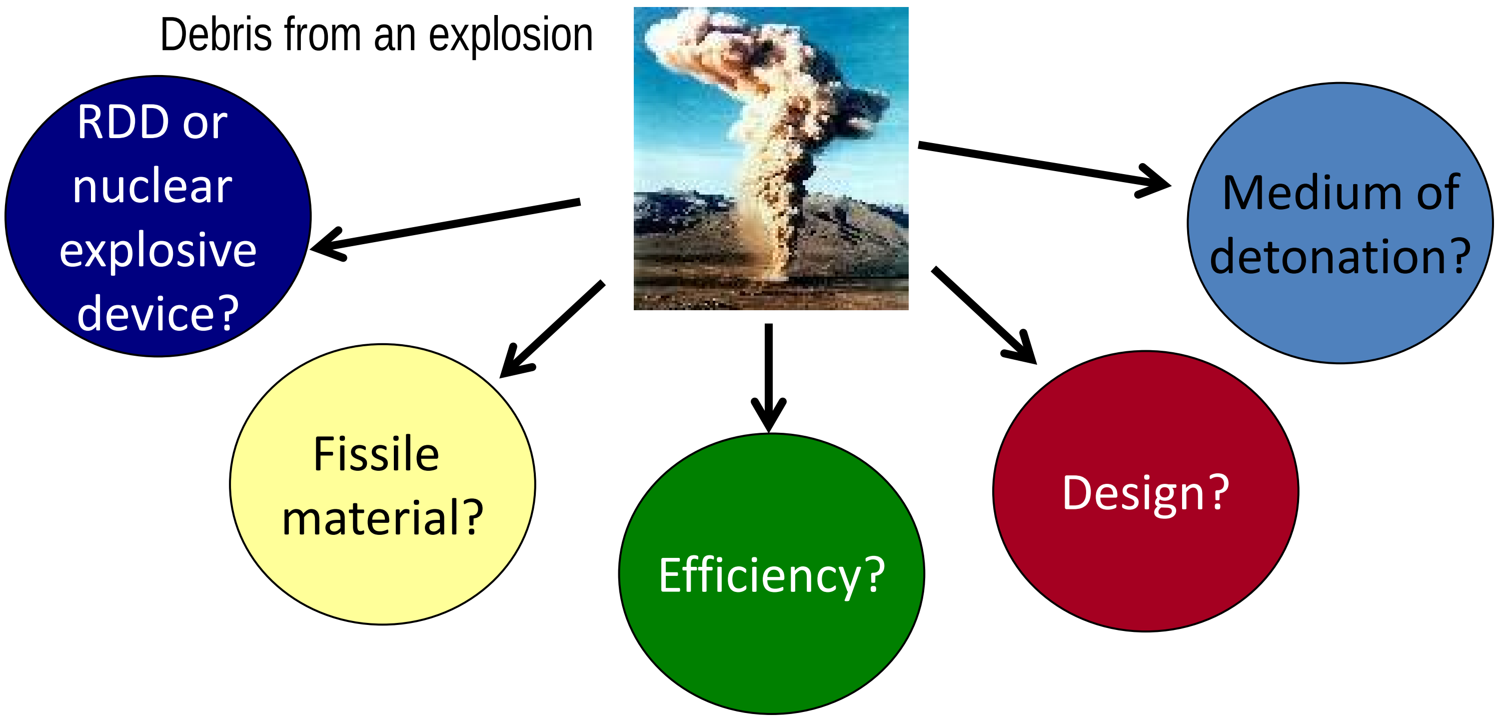
FPY (fission product yield) %



A_i mass of fission product

Forensic Investigation of Debris

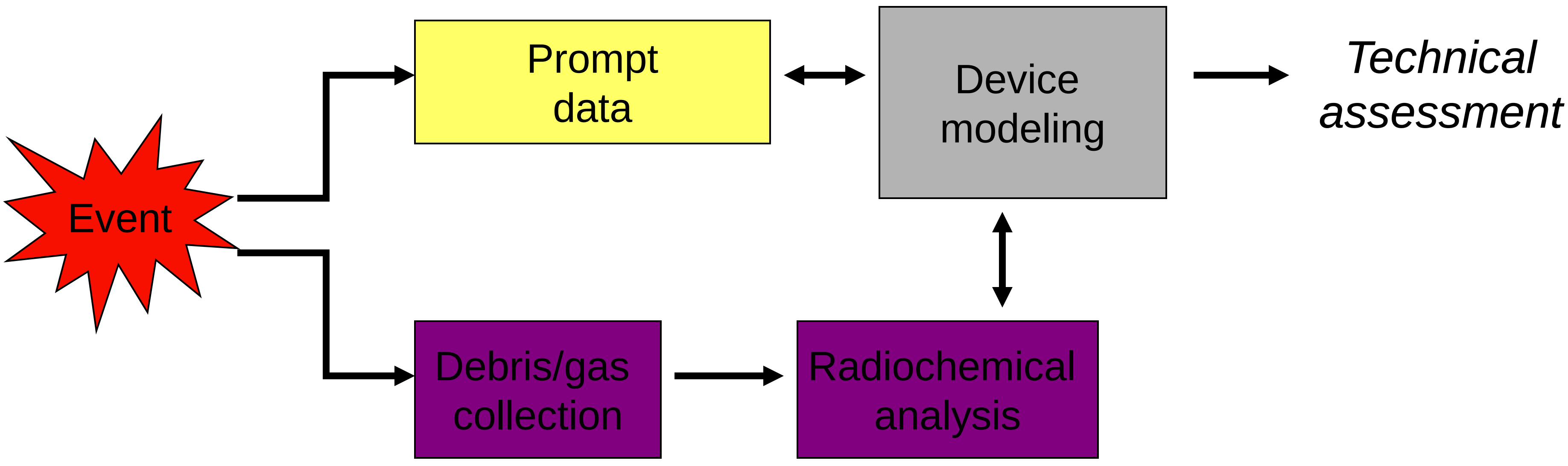
To perform forensic analysis on debris, using developed data interpretation techniques to learn about the device



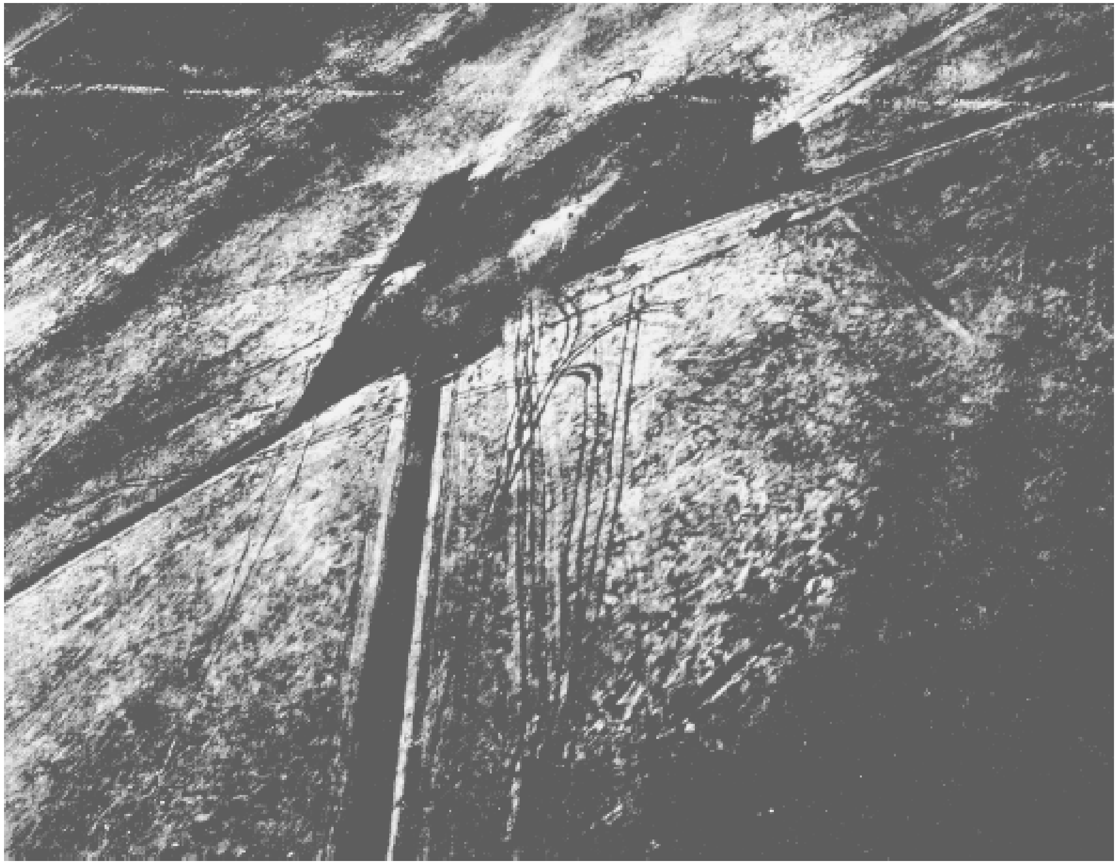
The big difference: we can still measure the efficiency, but we don't know the ingoing mass/type of fuel - now we need to get yield some other way

Technical approach

Requirements:
- Collection tools
- Yield information
- Analytical methods/facilities
- Assessment of radchem
- Modeling



Collections during the Trinity test

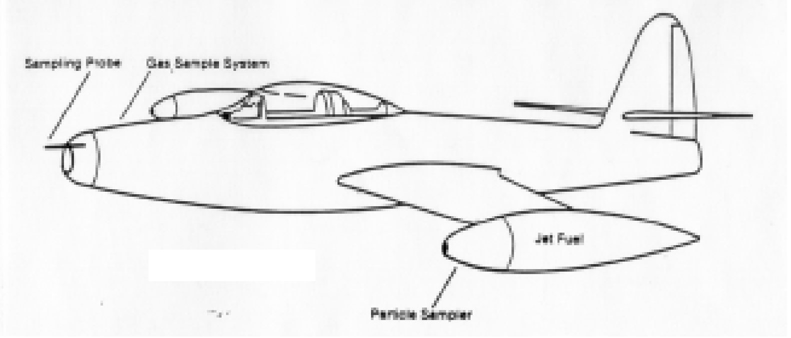


Sherman tanks were fitted with lead compartments to protect personnel during sample retrieval during the first day

The radiation field at ground zero was 700 R/h at t_0 + 1 day.

Collections during the Trinity test

Samples for analysis were collected from the cloud by a rocket or manned airplane

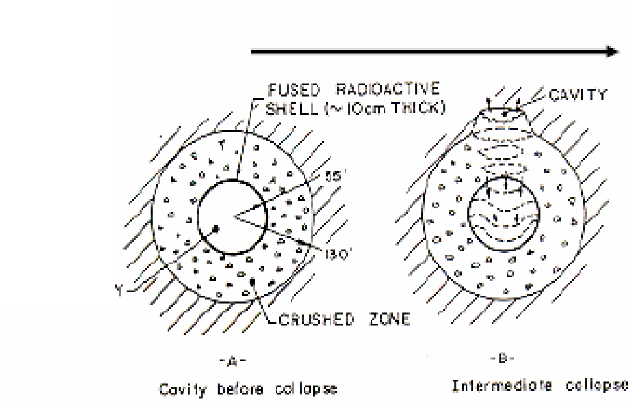


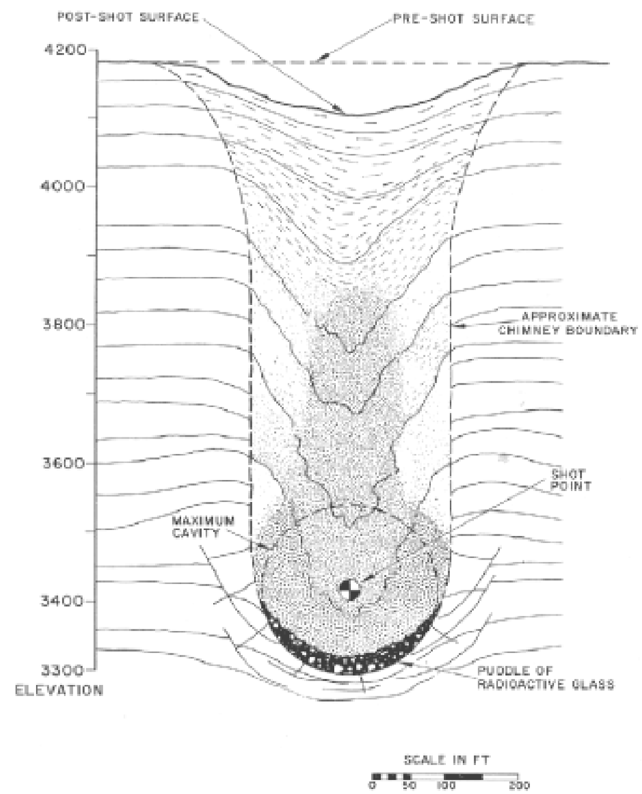
The pilot was in a shielded cockpit; plane was decontaminated and samples were removed before the pilot emerged to reduce dose

Testing Underground

After ratification of the Limited Test Ban Treaty, nuclear testing was conducted underground

Underground tests were conducted at depths of up to a mile:





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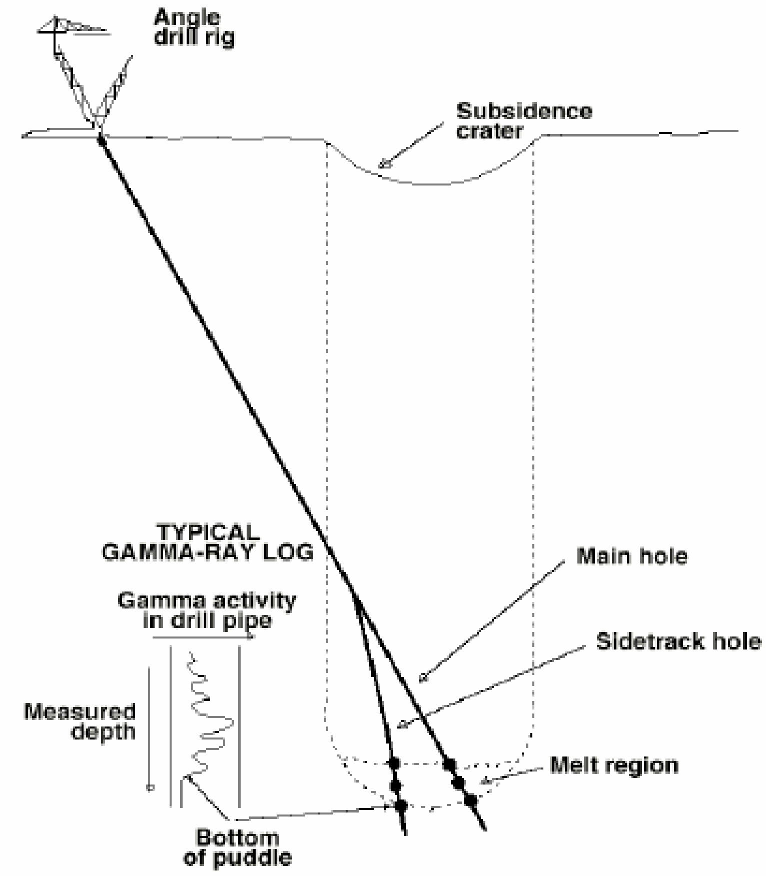
Sampling in the underground environment



"Drillback" conducted to retrieve samples

- Over a period of 1-3 weeks
- Gamma activity used to locate samples
- Samples retried from multiple locations through a main hole and a sidetrack hole

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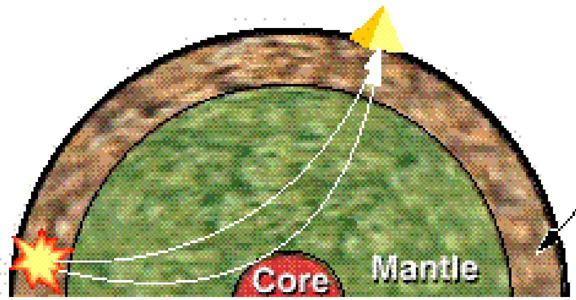
Operated by the Los Alamos National Security, LLC for the DOE/NNSA

Collections now – where and what to measure?

- Field deployed teams with equipment and instrumentation for sampling
  - Principal goal: field triage of samples
  - Sample selection based on data radiochemistry requirements
  - Initial sample analyses provide preliminary, low confidence characterizations
- We continue to develop:
  - Models/tools to characterize the site
  - Communications
  - New tools for sampling in many environments
  - What can we tell in the field
  - New signatures?

Seismic monitoring

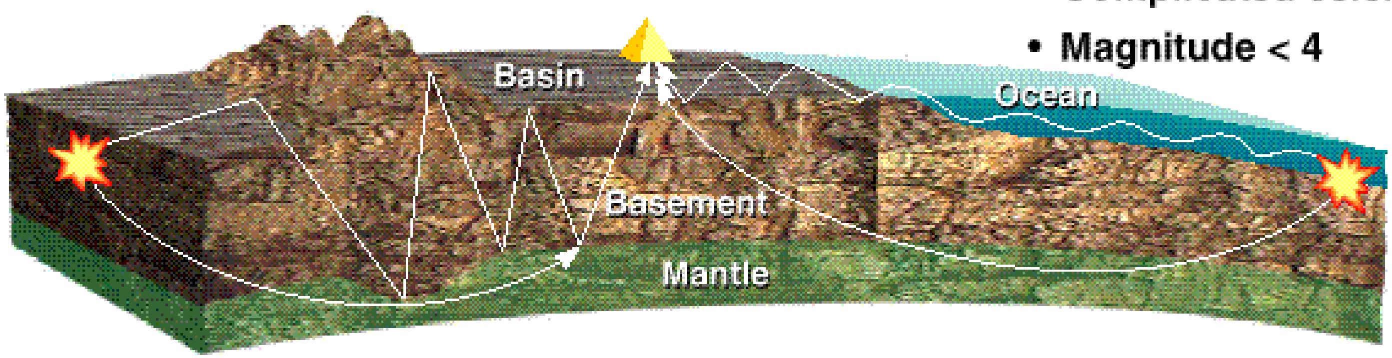
Old Regime -- Teleseismic



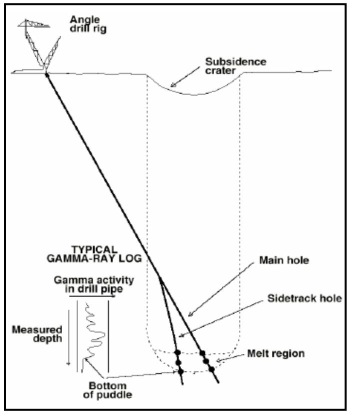
- Distances ≥ 2000 km
- Simple earth structure
- Simple seismograms
- Magnitude > 4

New Regime – Regional

- Distances ≤ 2000 km
- Complicated earth structure (Dependent on region)
- Complicated seismograms
- Magnitude < 4



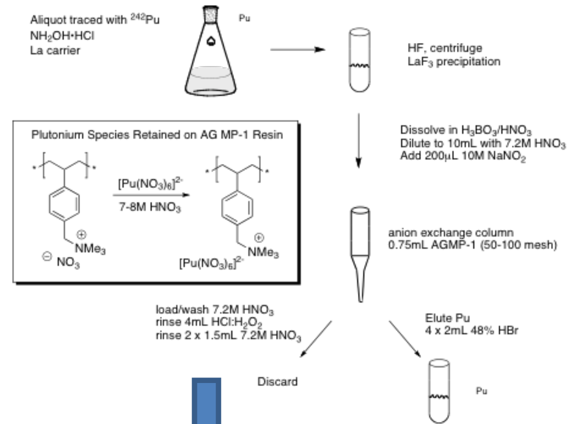
Weapons radiochemistry in the test era

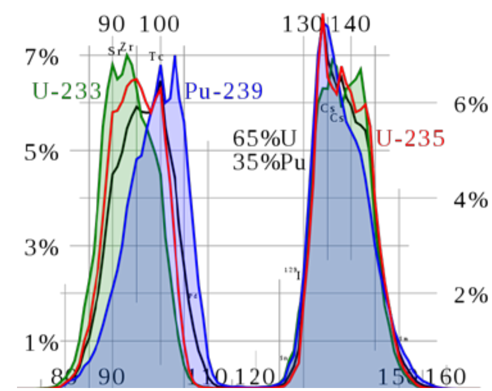


Sample recovery

Collections consist of very complex mixtures:

- **Homogenization**
- **Dissolution**
- **Separation**
- **Assay**





Not really this simple – other corrections apply

$$\varepsilon = \frac{\text{fissions}}{\text{Original atoms of fuel}}$$

$$\varepsilon = \frac{F}{F + p}$$

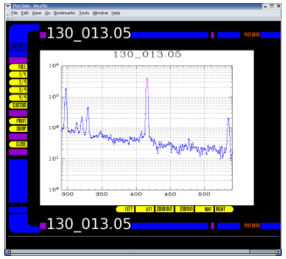
“***Measure fissions***” **in the sample, F**
Measure unburned fuel atoms, p

If total fuel known, can calculate total fissions (F_T), or energy release

Fixed laboratory analysis

Radiometric Analysis – Count Room

- Gamma, beta, alpha, neutron
- Trace levels to >10^{13} fissions
    - Operates 24x7x365
    - Analysis codes



Radiochemistry

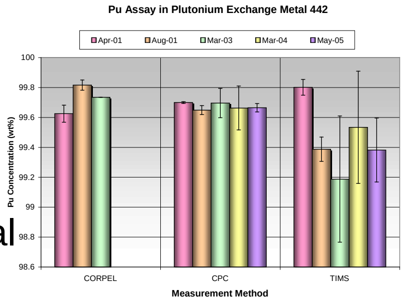
- Standardized radiochemical procedures
- Refractory matrices
- Segregated facilities for handling different activity levels

Mass Spectrometry

- Clean laboratory
- Modern Instrumentation
    - Specializing in actinide isotopic analysis
    - Years of routine environmental and bioassay monitoring experience

Sample Management and Quality Assurance

- Sample archives for environmental samples and debris
- Routine sample management activities
- QA/QC for ongoing operational missions
- Intercomparisons with otherlaboratories



Fractionation

Chemical Fractionation:

- All elements initially exist within a plasma
- As the fireball cools, less volatile (refractory) species condense first, followed by the more volatile elements, resulting in distortion of elemental distribution
- Volatile fission products do not "track" well with the debris; radiochemical samples are selected for their refractory character

Geometric Fractionation: Mixing may be incomplete in the debris field

Chemical fractionation

Chemical fractionation can occur if either precursor or final decay fission products are volatile

^{140}Ba 12.8 d — 0.24%

β

^{140}Cs 64 s — 3.05%

β

^{140}Xe 14 s — 2.59%

β

^{140}I 0.9 s — 0.11%

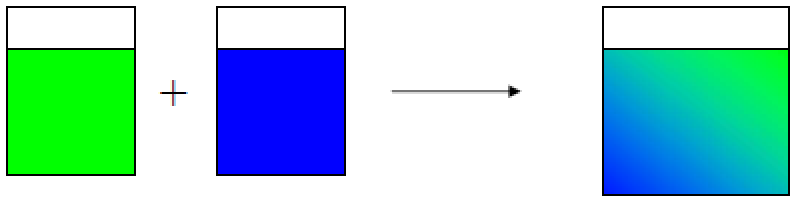
While the lanthanides and most actinides are refractory…

…The lighter rare earth elements can come from volatile precursors, and appear volatile

For the mass 140 decay chain associated with U-235 fission, most species come from volatile precursors

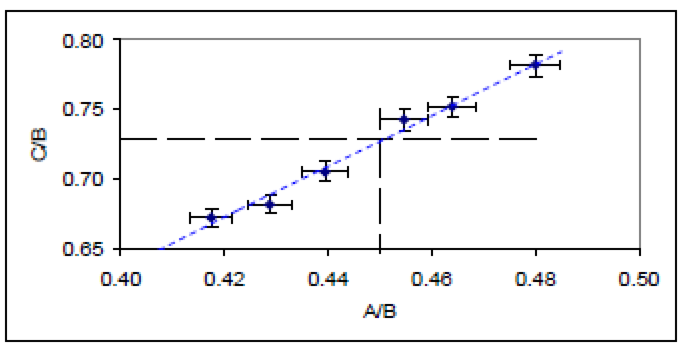
Geometric fractionation

Geometric fractionation can be determined through a “mixing analysis”, by comparing several independent samples:



2 Containers have mixtures of 3 isotopes: A, B, and C
We know the total amounts of A and B, A/B = .45
Both containers have some of isotope C but we don’t know how much

We collect samples from the mixture and plot A/B vs C/B



We can calculate C/B from the mixing line since we know A/B for the ideal mixture !

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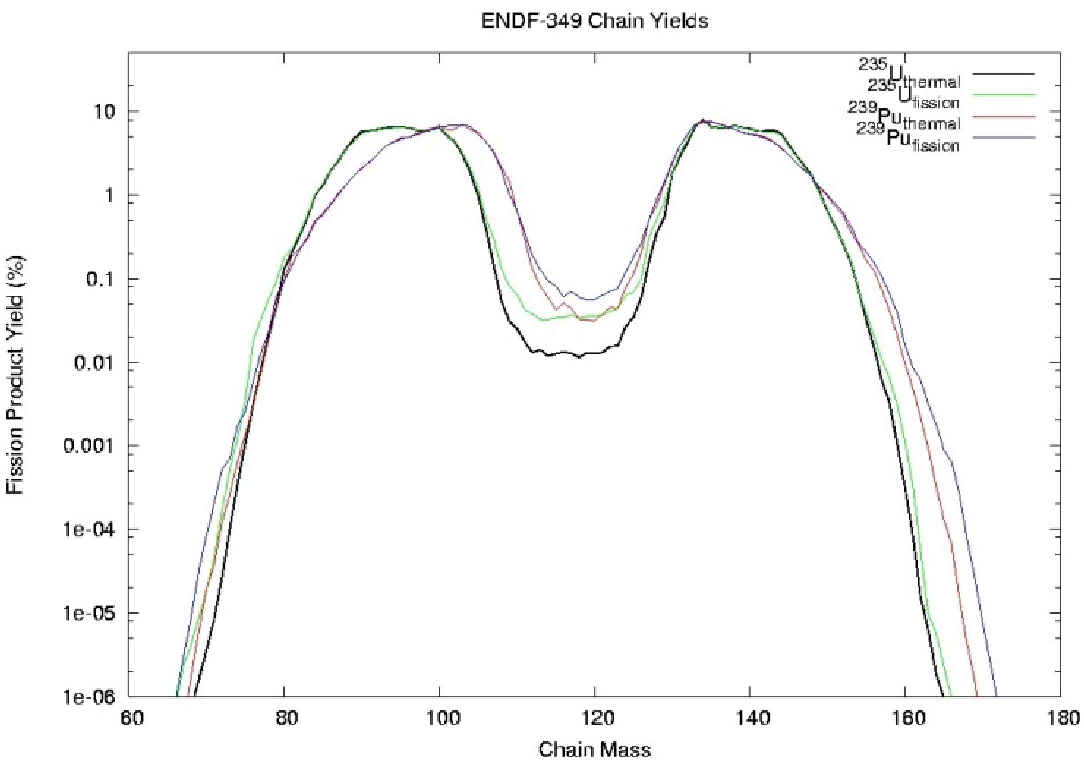
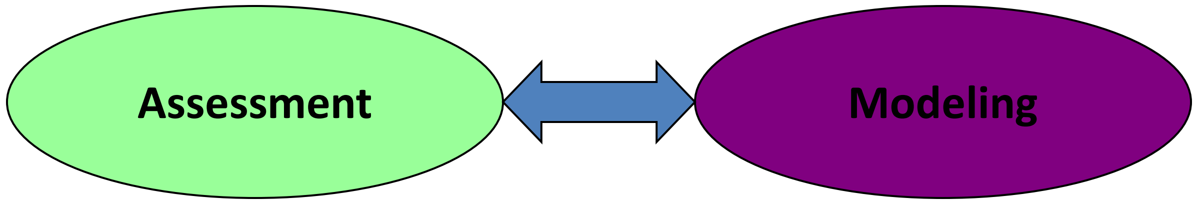
Fission product distribution relates to energy, fuel



- Energy is generated at different energies
- Energy distribution can change during the event
- Other reactions occur, e.g. neutron capture

Assessment and modeling



$$F_T = B \times \frac{N_{49}}{n_{49}/f}$$

N_{49} = total mass of Pu
n_{49}/f = fission per mass unit
B = 1/efficiency

- For a stockpile test, efficiency is characterized with knowledge of the mass of fuel and the yield.

- For an unknown event, we can essentially "go backwards":
With some independent estimate or measure of yield, and efficiency provided by radiochemistry, we can determine the ingoing mass.

<u>Parameters of interest:</u>

- **Components/masses**
- **Fission efficiency**
- **Level of sophistication**
- **Medium of detonation**
- **Information about nuclear fuel**

Technical opportunities – forensic analysis of debris

Was the detonation nuclear?

What was the fissile material?

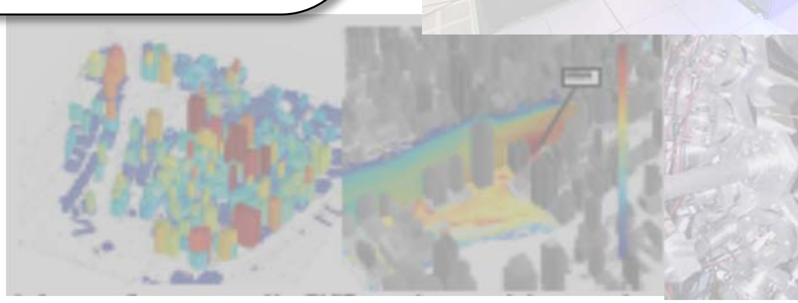
How well did the device perform?

What can we tell about the design?

What was the medium of detonation?

Collections:
- Models/tools for site characterization
- Communications
- Tools for sampling in differing environments
- New signatures

Analysis:
- Rapid/automated separations
- New instrumental methods
- Fieldable analyses
- New signatures



Modeling
- Code development
- Incorporating new nuclear data
- Modeling outputs
- Making tools more "usable"

The ability to address these needs founded in experience and infrastructure from enduring programs:

Our ability to characterize nuclear materials and processes relies on analytical methods from:

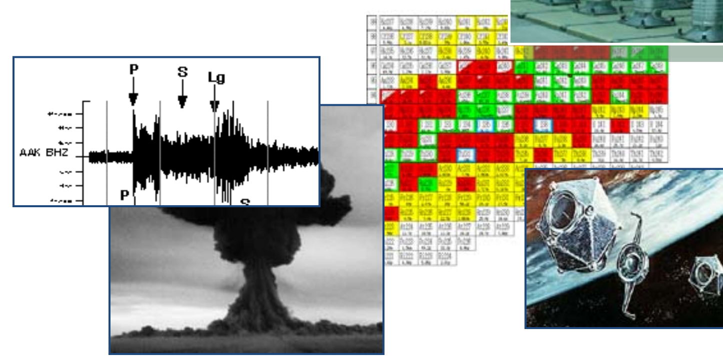
Certification of materials in pit production

Our ability to characterize signatures of worldwide nuclear materials production relies on skills built in:

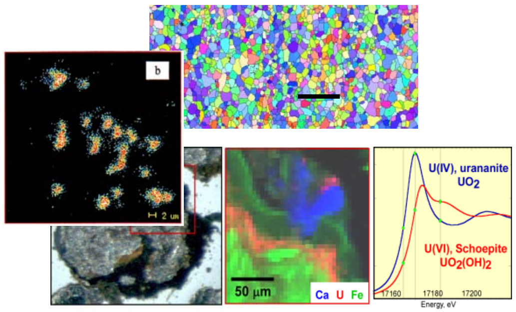
Support for international safeguards programs

Our ability to characterize the origins of a nuclear explosion is based on:

Underground test experience

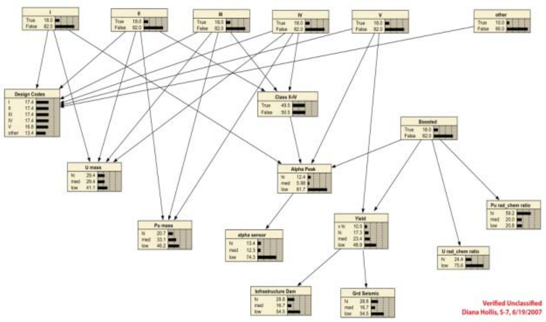


Strong research base advances these capabilities:

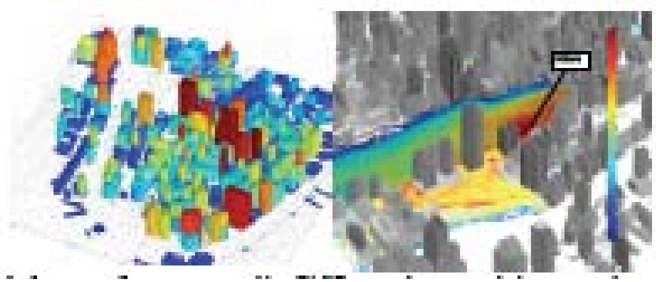


New materials characterization tools

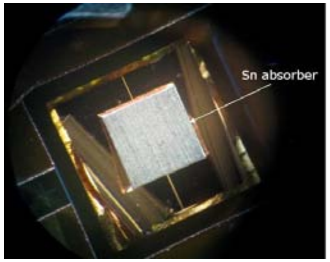
Ground-based measuremetns

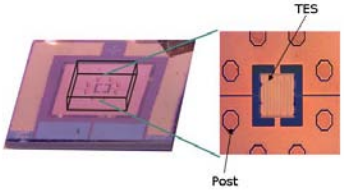


Statistical models for interpretation, confidence levels

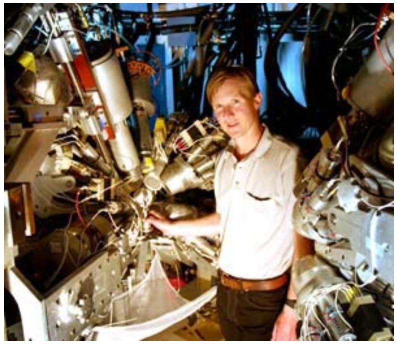


Dispersion models to guide collections



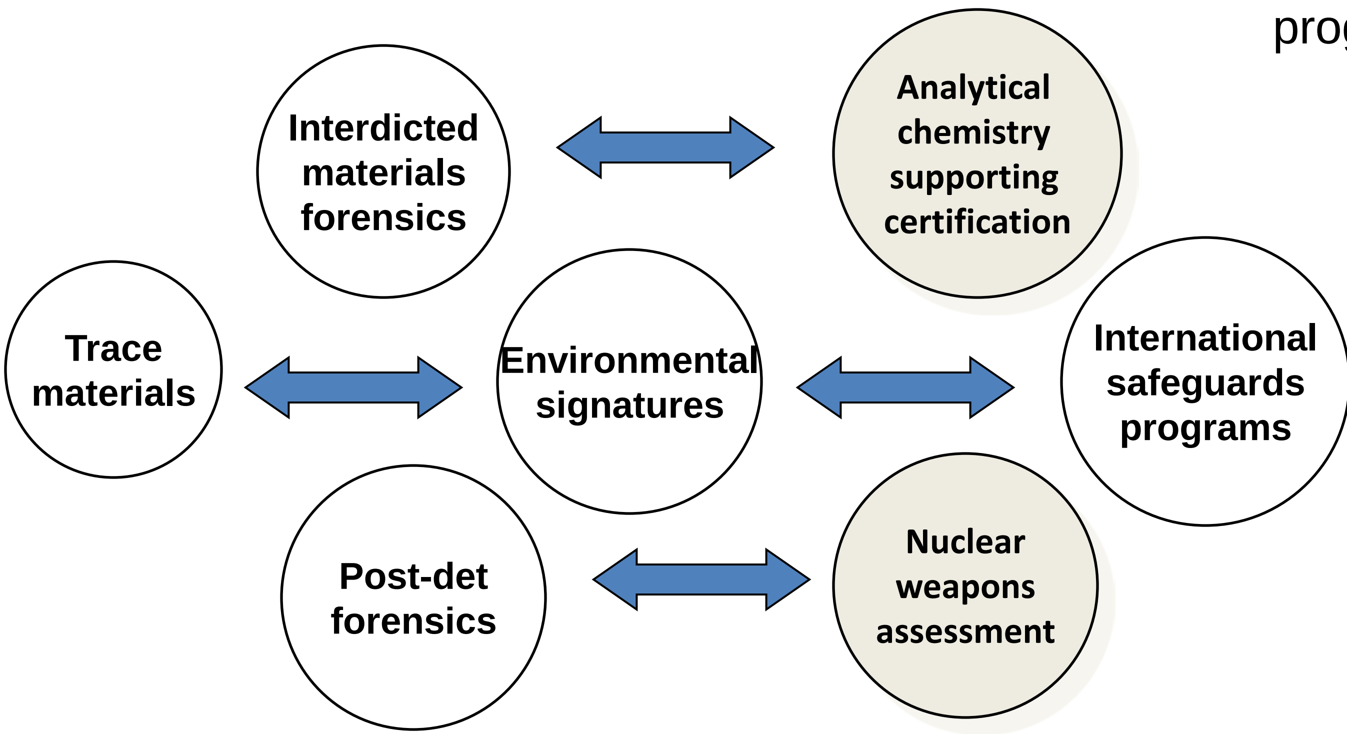


Improving sensitivity of measurements



Improved nuclear data for models

Capabilities supported by synergistic programs



Return to the weapons program:

- Leverage support for plutonium sustainment
- Support for the development of advanced analytical methods
- Support for core competencies not currently robustly supported
- Providing challenges to help develop the next generation of scientists